Art. III.—*On the Age and Physiographic Relations of the Older Basalts of Greensborough and Kangaroo Ground, and of certain Basalts at Bundoora and Ivanhoe.*

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Introduction and Previous Literature.

The Kainozoic basalts of Victoria have hitherto been divided into two main series, the Older Basalt and the Newer Basalt. The former is represented by the isolated patches lying mainly to the east of Melbourne, and the latter by the great volcanic plains to the west of the same city.

Whilst, however, these two principal series have been recognised, some suggestions have from time to time been made that there is an intermediate series. Thus, as pointed out by Mr. T. S. Hart in his "Volcanic Rocks of the Melbourne District,"[1] the older volcanic rocks are divided into two groups on the Geological Survey Maps—viz., Older Volcanic and Lower New Volcanic. Mr. Hart shows that the largest area of the Older Basalts, near Melbourne, lies along and to the east of the Saltwater River, and reaches down to Melbourne, reappearing beyond the Yarra at Emerald Hill; and that the greater part of it is coloured and lettered on the maps as Older Volcanic, the south-eastern end is coloured and lettered as Lower New Volcanic, and the middle is coloured Lower New Volcanic and lettered Older Volcanic. Mr. Hart concludes that from the sections round Melbourne there is a series of older volcanic rocks, overlaid by marine Tertiaries, and perhaps a second series before the newer volcanic. Mr. Hart also discusses the age of the Greensborough older series of basalts, as will be shown later.

Messrs. Hall and Pritchard in their paper on the Tertiaries in the neighbourhood of Melbourne[2] also point out (p. 189) that the volcanic rock at South Melbourne and West Melbourne is coloured on the Geological Survey Quarter Sheets as Lower Volcanic—i.e., Lower Newer Volcanic—and is so lettered except on Quarter Sheet

1 Vict. Nat., vol. xi. (1894), p. 75.

2 Proc. Roy. Soc. Victoria, vol. ix. (N.S.), 1896, pp. 187-229, pl. 8.

The Greensborough Older Basalts.

These rocks form a series of small isolated patches on the tops of the hills on each side of the Plenty River in the neighbourhood of Greensborough and Janefield. They were mapped in the early days of the Victorian Geological Survey, and were re-examined by the writer whilst mapping the country to the east of the Plenty River prior to his departure in 1911 for Western Australia.[1] Associated with them are the Kainozoic gravels and sands shown on the Survey Quarter-Sheet. As already noticed, Aplin and Hart doubt whether the basalts rest upon the sediments. At the time of my examination of the country, no sections were available showing the actual relations, but from an exhaustive examination I have no doubt that the basalt overlies the sediments.[2] This opinion is based upon the relative positions of the two rocks throughout the area, but it is supported by the fact that no basalt pebbles in the sediments have been discovered by the writer. If the basalt were the older, we should certainly expect some of its pebbles to be included in the sediments.

If the relations between the rocks be as stated, then the age of these Kainozoic sediments becomes an important question as regards the correlation of the basalt, and merits some attention.

Generally similar sedimentary rocks are found to the south in isolated patches, forming as a rule the caps of hills, such as at Heidelberg, Preston, Northcote, Studley Park and Royal Park. These appear to pass into the more or less continuous sheets to the south-east of Melbourne, and there can be little doubt that the whole of these rocks were originally unbroken on the Nilumbik Peneplain,[3] the more northern areas probably being of freshwater origin, whilst the southern ones are in part at least marine. The country has since been much dissected, especially in its northern parts, with the result that the sediments in places now form merely the caps of the hills.

The sediments of the Greensborough area are now disconnected by erosion, but are found high up the hills at apparently the same

1 Portion of this country has, I understand from Prof. Skeats, been independently mapped by Mr. Junner of the Melbourne University (he being unaware of my work amongst the basalts of the district), and a paper thereon has been read by him before this Society. At the time of writing (6th March, 1913) this paper has not been published, nor has it been seen by me, so that both Mr. Junner's and my own conclusions are each independent of the other's.

2 In places the basalt rests directly on the Silurian. The explanation is that either from the contour of the country, the gravels and grits never covered these particular places, or that they have been removed by denudation before the flow of the basalt.

3 For a definition of this peneplain, see the writer's paper on the Physiography of the Yarra previously cited, p. 477.

general level. The latter also appears to be continuous with that of similar deposits to the south referred to above In their lithological and general characters, the deposits are similar, except that in the Greensborough area they are much coarser-grained in places, consisting largely of very heavy gravels.[1] This, however, is what would be expected on approaching the hills (to the north), from which the rocks are derived. The most reasonable inference is that the Greensborough sediments belong to and are of the same age as those to the south. These, by the fossils obtained at Royal Park and Beaumaris, have been placed as Kalimnan, so that if the Greensborough gravels and sands belong to this period, the Older Basalt of the district may be considered as Kalimnan, or younger.

The Older Basalt at Royal Park and other localities farther west underlies the Barwonian, hence it must be of this or of an earlier age. There is therefore a very considerable time gap between the Older Basalt of Royal Park, Saltwater River, etc., and the Older Basalt of Greensborough.

The latter rock is much older than the Newer Basalt of the plains. The Greensborough area clearly shows (as pointed out by Mr. Hart) that before the eruption of the Newer Basalt, the Older Basalt had been much denuded and the country deeply dissected. A large time gap also therefore exists between the Older Basalt and the Newer Basalt of the Greensborough district. There is thus evidence of three distinct basalt periods, separated by wide intervals of time, in the neighbourhood of Melbourne.

If the Older Basalt of Greensborough were of the same age as that of Royal Park, the underlying sediments would be much older than Kalimnan, and would probably be contemporaneous with the sedimentary beds below the Royal Park basalt, but the available evidence points in the writer's opinion rather to Kalimnan age than to a much older period.

In the Greensborough area, most of the Kainozoic sediments are closely associated with the basalts. The latter have apparently acted as protective caps, and when the basalt is removed the sediments soon follow. Farther south there are numerous outcrops of sediments uncapped by basalt. Greater thickness of sediments in this direction (towards the sea) would, however, be expected, and this thickness would temporarily save some rocks from removal by denudation. In view, moreover, of the evidence brought forward in this paper, it is impossible to say to what extent basalt may have overlain the sedimentary rocks.

1 Similar gravels are also found at Kangaroo Ground.

The Kangaroo Ground Older Basalt.

The main portion of this basalt occupies a fairly extensive belt of high country a few miles to the east of the Greensborough basalts. As seen in the road cuttings, it is very vesicular, and considerably decomposed in parts. In the former character it differs from the Greensborough Older Basalts, as the latter, so far as observed, are generally dense.

Beneath the basalt are some gravels, grits and sands, which have in places been worked for gold. These sediments, together with their silicified products, quartzites, can be noticed at the edges of the basalt on the northern and eastern sides of the main outcrop. Quartzite boulders are found in other parts, and in the township of Kangaroo Ground there is a rather extensive outcrop, which also apparently underlies the basalt.

An actual section of the basalt covering the sediments is seen to the east of the small quarry reserve in Allotment 16, Section III., Parish of Nillumbik. The basalt cap here is only a few yards in diameter, but it rests on grits and gravels of an exposed thickness of about 16 feet, so that any doubt as to the relations of the two rocks is set at rest.

The Geological Surey has marked on the parish map of Nillumbik the "probable course of lead" under the basalt, thus indicating a belief in the existence of an old buried river channel. The basalt at Kangaroo Ground certainly in parts lies on a very uneven surface, as may be seen on the main road running north to the township from Eltham. By Weller's Temperance Hotel, at the foot of a long hill, the basalt outcrops and overlies gravels, whilst towards the top of the same hill going north it rests on Silurian rocks. In this uneven surface, it appears to differ much from the Greensborough Older Basalts. Elsewhere, however, in the vicinity, the general surface on which both the basalt and gravels lie seems moderately level.

The question of the age of the Kangaroo Ground basalt is not easily answered. The writer, in his paper already referred to on the physiography of the Yarra Basin, regarded this rock (through adapting the current ideas of its age as that of the typical Older Basalt of Royal Park, etc.), as a monadnock on the Nillumbik Peneplain, and therefore older than the latter. The cap of Kainozoic sands and gravels around Melbourne rests on the peneplain, and is therefore younger or at least coincident with the final stage of formation of the peneplain. Considering the Greensborough gravels and sands as part of this cap, makes the Older Basalts of the same

district younger than the peneplain; whilst if the Kangaroo Ground basalt be a monadnock on the peneplain, there is a great gulf between the respective Older Basalts of the two places. If, on the other hand, it be not a monadnock, but part of a flow subsequent to the formation of the peneplain, both it and the Greensborough rocks would probably be of the same age, but separated from the Royal Park flow by a great interval of time.

The point might be satisfactorily settled if the age of the sediments below the respective basalts at Kangaroo Ground and Greensborough could be determined beyond doubt, but unfortunately no fossils have been discovered at either place, and thus the most reliable proof is absent.

The proximity of the two areas, the generally similar characters of the underlying sediments, and the roughly level, continuous surface over which the basalts have flowed suggest their identity in age. In favour of their difference is the uneven valley-like surface on which the Kangaroo Ground basalt in part rests, and the discrepancy in the character of the rocks (vesicular and dense) already noted, but these are of a somewhat frail nature on which to make a great time gap. Provisionally, therefore, these basalts may be held to be of the same age, and as the Greensborough Older Basalt belongs probably to the Kalimnan or later period, the Kangaroo Ground basalt must tentatively be placed there. If this be correct, the latter is not a monadnock on the Nillumbik Peneplain.

No distinct vents have been discovered in the basalts of Greensborough or Kangaroo Ground. Garden Hill, at the latter place, rises considerably above the general level of the surrounding basalt and it is just possible that this may represent the worn-down vent from which the lava was spread over the country.

Streams cut through the Older Basalt at Greensborough, but are deflected away from that at Kangaroo Ground. Either a monadnock on the old peneplain or a high mass (such as exists), due to being the remains of a vent, would cause this peculiarity.

The Mount Cooper Newer Basalt.

As previously indicated, the basalt forming the cap of Mt. Cooper, Bundoora, is shown on the Survey Quarter-Sheet as continuous with the Newer Basalt flows on the plain to the west. On a visit to the locality some years ago, the writer accepted this view, but in consequence of subsequent examination of the Greensborough basalts, and the high-level basalt at Ivanhoe, together with the distribution of the basalt around Mt. Cooper, as shown by the map,

some doubt has arisen as to its correctness. On a recent visit to Melbourne, the writer intended to visit the ground, but unfortunately time did not permit. The question is, however, now brought forward as a suggestion for further investigation.

Mt. Cooper is a rather prominent landmark, rising to a fair height above the Newer Basalt of the Darebin Creek valley, and having steep northern and western faces. There is a large patch of Kainozoic sediments (most of which have been converted into quartzite), which rest on the Silurian rocks of the district, and underlie the basalt. This quartzite outcrops freely on the northern, western and southern slopes of the hill, and is found right in the bed of the Darebin Creek to the west.[1] These silicified gravels and grits are no doubt part of, and originally continuous with, the Kainozoic sediments of Preston and Greensborough, to which reference has already been made.

The basalt cap is at the northern end of the hill, and is probably from 40 to 50 feet thick at the highest point. This basalt, when examinued *in situ*, is, so far as observed, dense and non-vesicular. Its boundaries are clearly shown on the northern, southern and western sides, where the quartzite already referred to crops out from beneath the basalt. To the west, in the valley of the Darebin Creek, is the low-lying lava flow, the typical Newer Basalt of the district, from which the high basaltic cap of Mt. Cooper is separated by the quartzite.

According to the Survey map, the basalt of the hill is continuous with the lower basalt at its north-eastern end, and on this ground no doubt, the higher basalt has been mapped as Newer Basalt, and the hill consequently regarded as a volcanic vent. An important question therefore is whether the two basalts are actually connected or not.

At first sight there appears to be no doubt that such a connection exists as although an actual outcrop cannot be continuously traced, the heavy black soil resulting from the decomposition of basalt forms an unbroken line on the north-eastern face. In addition, near the top of the Mount, and on the same face, numerous pieces of very vesicular basalt of low specific gravity, which might for convenience be called basaltic pumice, occur. This is somewhat suggestive of a vent in the neighbourhood. There is also a low hill between Mt. Cooper and the main road to the east, rising above the level of the low-lying basalt. This hill has highly vesicular basalt, which is apparently connected with the lower flow.

1 This shows that at this locality the Kainozoic sediments were deposited on an uneven surface, or that they have been let down by faulting.

On the other hand, the Mount has been well dissected on most sides, and the basalt appears to be lying on the quartzite. If a plug exist, it occurrence has not yet been actually demonstrated. Again the basalt on the top of the quartzite, when examined *in situ*, is dense and non-vesicular, in this respect in hand specimens, resembling more the Greensborough Older Basalt than the typical Newer Basalt. It also occurs at such a height that if erosion had proceeded so far as to remove all traces of basalt on the north-eastern slope, the high basalt would certainly have been regarded merely as another outlier of such Older Basalt of Greensborough. It is for these reasons that the writer ventures to doubt the correctness of the Survey interpretation.

In the absence of a sufficient examination of the area since this doubt arose, a definite opinion on the point cannot be offered, but as a hint to anyone taking up the investigation, attention should be paid to the low hill to the east, which may be the remains of an old vent of the Newer Basalt period. If so, the occurrence of such basalt above its general level might be explained, and at the same time make it possible for the basalt on the top of Mt. Cooper to be another outlier of the Older Basalt of Greensborough or perhaps the plug of an old vent of such Older Basalt, but there is little more (if any) ground for the latter alternative than for any of the basalt caps of the Greensborough area.

Microscopical examination might throw some light on the question, and the small patches of Newer Basalt on the eastern side of the main road at Bundoora (which the writer has not seen) should also be studied.

The Ivanhoe High-Level Basalt.

On several occasions some years ago, the writer endeavoured to locate the "basalt boulders" marked on the Quarter-Sheet. The "siliceous conglomerate" was easily fixed by an outcrop on the roadside, but no trace of the basalt could be found, and the matter was dismissed as a mistake of the field geologist or draftsman. Some time later, however, on happening to pass that way again, several holes up to about 4 ft. deep were being dug in connection with the formation of a nursery, and in these holes the "basalt boulders" revealed themselves, thus offering another testimony to the remarkable accuracy of the early Victorian Geological Survey. The basalt was close to the siliceous conglomerate, and apparently only a few yards in extent.

The "basalt boulders" consisted of rounded, semi-rounded and angular blocks, having on the average a diameter of about 10 inches

of hard, non-vesicular, dense basalt. Some blocks were polygonal in shape. The writer has no doubt that these boulders are not waterworn, but are the remains of basalt *in situ*, jointed into small vertical columns, and then weathering into the observed forms by exfoliation, i.e., spheroidal weathering.

The rocks were found near the crest of the ridge to the east of the Darebin Creek, and high above and disconnected from the Newer Basalt flow of that valley.

The actual relation to the silicified sediments could not be seen, but the latter may be taken to represent a small altered patch of the ordinary Kainozoic sediments of the district. The silicification is apparently connected with the basalt, and the latter would probably therefore be younger. It is evidently older than the Newer Basalt, and its most likely age is that of the Older Basalt of Greensborough, and of the cap of Mt. Cooper, if the latter ultimately turn out to be of the same age as the former, the likelihood of which is, in the writer's opinion, strengthened by the Ivanhoe example. The possibility of the basalt being a volcanic plug of the Greensborough Older Basalt period must also be borne in mind, although there is no direct evidence on the point.

It is interesting to observe that only at this locality (where basalt is associated with them) are the Kainozoic sediments of Ivanhoe and Heidelberg silicified to such an extent as to merit the term quartzite being applied to them. Yet at Greensborough basalt caps are numerous, and scarcely any silicification has taken place, but at Kangaroo Ground both silicified and unsilicified Kainozoic sediments underlie the basalt. At Mt Cooper the underlying sedimentary rocks have been extensively silicified. Mr. Armitage[1] has suggested a cause for the silicification of similar rocks in the Essendon district, but the matter cannot here be discussed.

The Physiographic Relations.

As we have seen, the question of the age of the basalts and sediments is bound up with the physiography of the district.

The following points appears to be well established. To the north, east and south of Melbourne, the higher hills are capped by Kainozoic sands and gravels, which were originally continuous and rested upon a practically level surface of the older rocks, this surface representing an old base-level of erosion, which stretched far up the Yarra valley, and which for convenience has elsewhere been called the Nillumbik Peneplain. These gravels and grits around

1 Vic. Nat., vol. xxvii. (1910), p. 92.

Melbourne are in part marine and in part freshwater. They were laid down on the Nillumbik Peneplain at the base-level of the latter. Subsequently the country was elevated, and a fresh cycle of erosion commenced, with the result that the Kainozoic sediments have been partly broken up into the present disconnected caps on the hills, and in the resulting valleys the Newer Basalt has flowed. Judging by what are regarded as the marine representatives of these sedimentary beds at Royal Park and Beaumaris, their age is Kalimnan. The Older Basalt at Royal Park is clearly older than the Kalimnan beds there, as the latter overlie the Barwonian, and these in turn the basalt.[1]

Passing now from these fairly well established conclusions, reasons have already been given for believing the Kainozoic sediments of Greensborough, Ivanhoe and Mt. Cooper to be Kalimnan; for classifying the overlying basalts at Ivanhoe and Greensborough as Kalimnan or later; for considering the possibility of the Mt. Cooper basalt being of the same age; and for provisionally placing the Kangaroo Ground sediments and basalt with the similar rocks of Greensborough.

From physiographic considerations it would seem that the Older Basalts, the subject of this paper, must have been poured out before the underlying sediments were broken up by erosion, and consequently before or soon after their uplift from base-level; for if any great interval elapsed between the uplift and the basalt flows, denudation would have brought about such inequalities of the land that the basalt, instead of as a rule, now regularly capping the hills, would have been found also in the valleys, but of this there is no evidence, except in part at Kangaroo Ground, as already recorded, which, however, may be due to some local cause.

Summary.

Gravel, grits, sands and their alteration product, quartzite, are found at Ivanhoe, Mt Cooper, Greensborough and Kangaroo Ground at high levels, associated with the basalts. The latter overlie the sediments at three of the localities, and at the fourth (Ivanhoe), the same relation probably holds good.

No fossils have yet been discovered in these sedimentary rocks. In their absence, the evidence points to those at Greensborough and Mt. Cooper being continuous with and of the same age as those farther south (which include the Ivanhoe area), and which are re-

1 As to the general Kainozoic history of the country around Melbourne, see "Victorian Hill and Dale" and other writings by Dr. T. S. Hall.

garded as Kalimnan. The overlying basalt at Greensborough and that at Ivanhoe must therefore be Kalimnan or younger, but it is uncertain whether the Mt. Cooper basalt belongs to the same series or to the Newer Basalt period.

The Kangaroo Ground sediments and covering basalt are on a balance of probabilities provisionally placed with the similar rocks of Greensborough.

The evidence therefore shows a series of basaltic outliers, which point to a distinct period of vulcanicity between the typical Older Basalt of Royal Park and the Saltwater River, and the Newer Basalt of the plains, the intermediate period being separated from each of the others by a great time gap. It is suggested that the terms Older Basalt and Newer Basalt be retained for the rocks above indicated by those names, as they are now well established and understood, whilst the term Intermediate Basalt be used for the basalts of the intermediate period.

On the above reading, the Kangaroo Ground and other basalts cannot be considered as monadnocks on the Nillumbik Peneplain, as they are younger than such peneplain.

Garden Hill at Kangaroo Ground may be a worn-down vent of the Intermediate Basalt.

From the physiography of the district it is inferred that the Intermediate Basalt was poured out before or shortly after the uplift of the Nillumbik Peneplain.

In conclusion, it is well to state that the want of definite conclusions on the various points raised in this paper is chiefly due to two reasons—first, the unsatisfactory character of the evidence itself, and second, the incomplete examination of the ground by the writer on account of his removal from Victoria to Western Australia.

Sufficient data have, however, been brought forward to show that not only a thorough investigation from all points of view of the basalts and associated sediments of the area dealt with in this paper and of adjacent districts is required, but also that the Older Basalts of the State as a whole should be subjected to a close re-examination as opportunity offers.

The difficulties attending attempts to fix the age and stratigraphical relations of the Victorian basalts have been pointed out by Prof. Skeats.[1]

1 Pres. Add. (Sec. C), A.A.A.S., Brisbane, 1909, p. 199 *et seq.*